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NRL REPORT 4195

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Sound Division

CONTENTS

ABSTRACT

In hunting for bottom mines with acoustic means, bottom reverberation—or "back-scattering"—forms the background in which the mine echo must be detected. In spite of its manifest importance in determining equipment design parameters, it appears that the back-scattering of sound by harbor bottoms has not been systematically investigated. The aim of the present study has been to obtain a knowledge of the variation of back-scattering with angle, frequency, and bottom type.

Measurements at eight locations in Narragansett Bay were made with a tiltable searchlight transducer at frequencies in the range 10 to 60 kc, and between 10° and 90° grazing angle. The bottom types varied from rock through sand to mud. The results are expressed in terms of a coefficient S, which might be called the "scattering strength" of a square yard of bottom. S was found to decrease with decreasing grazing angle, and to be substantially independent of frequency. At a grazing angle of 30°, S was found to vary from approximately -13 db for a rocky bottom to about -30 db for a muddy bottom.

S is analogous to "target strength" for sonar targets, and its value determines the maximum size of the area which can be insonified without losing the target echo amid reverberation. An example of the use of this parameter in equipment design is given.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem S02-03
RDB Project NR 522-030

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THE BACK-SCATTERING OF SOUND BY HARBOR BOTTOMS AND ITS APPLICATION TO ACOUSTIC MINE HUNTING

INTRODUCTION

In acoustic mine hunting, reverberation, or more properly "back-scattering," forms the background in which the echo from the mine must be detected. This scattering is produced by the bottom on which, or in which, the mine is situated. In active sonar mine hunting the principal problem is to distinguish the mine echo from an "echo" having nearly, but not entirely, the same qualities as the target echo. This "echo" is produced by a rough surface in intimate contact with the target. The problem is identical with the detection by radar of a snorkeling submarine amid the clutter produced by the surface of the sea.

It is an understatement to say that, up to this time, acoustic mine hunting has not been entirely successful. The type AN/UQS-1, originally designated UOL, equipment now in fleet use, while performing well in some instances, has not been able in other situations to locate mines at usable ranges. The British developmental equipments Types E and F have similarly proven unsuccessful under many conditions.

The most common cause of the failure to detect mines over some types of bottom appears to be the scattering produced by the bottom itself. It seems evident, therefore, that before a completely adequate mine hunting sonar can be developed, attention must be directed to those features of the reverberation which obscure the echo. One of these features is its intensity. It is thus important to study the variation of intensity with frequency, angle of incidence of the sound beam, and type of bottom. With these things understood it will be possible to design a mine-hunting set with some assurance of its performance in advance of development.

With this eventual objective in mind, it seemed desirable, therefore, to undertake in a small way a systematic measurement program of back-scattering over actual bottoms, and over a reasonably wide range of practical operating frequencies, and to express the results in fundamental terms that have practical usefulness.

METHOD EMPLOYED

Since the dependence of back-scattering upon grazing angle of the sound beam at the bottom is one of the important factors to be determined, the direct approach to the problem is to take a "searchlight" (or circular piston) transducer, tilt it in the vertical plane by assignable amounts, and measure the amount of back-scattering for different angles of tilt. This method was used in the present work. In addition, frequency and pinglength were changed in order to study their effect on scattering levels.

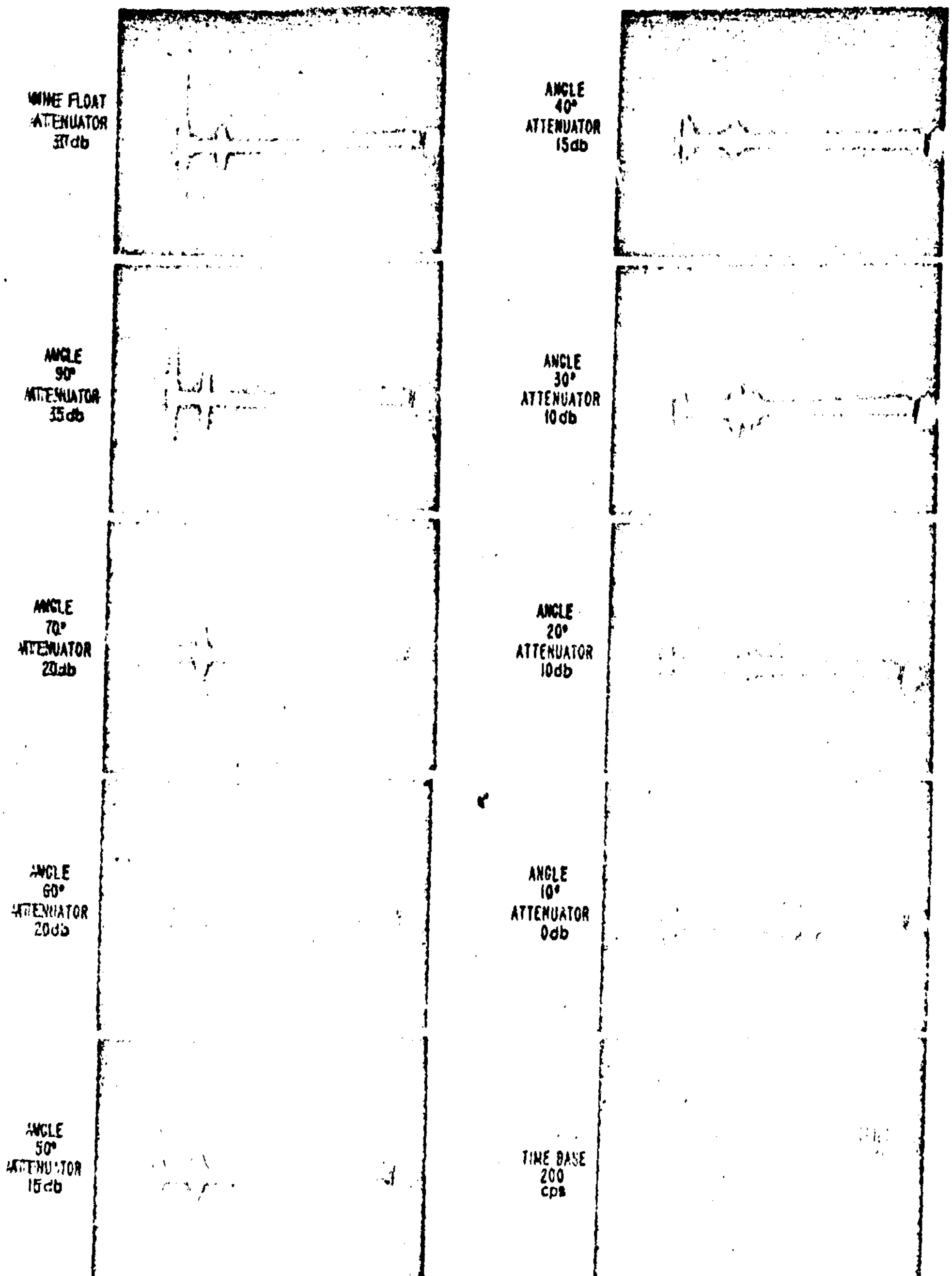

Figure 1 - Typical photographs of back-scattering for various tilt angles. Water depth below transducer, 47 feet; distance, transducer to reference target, 31 feet; area C.

A round-faced ADP transducer (NRL-XQB-27) with an active face diameter of 13 inches was mounted on a vertical shaft in such a manner that it could be rotated in the vertical plane. The lower end of the shaft and the transducer were at a depth of 7 feet below the surface. A handwheel and a graduated circle at the top end of the shaft permitted accurate positioning in tilt. Short sound pulses of adjustable length from 0.5 to 5 ms and of adjustable frequency from 10 to 60 kc were emitted from the transducer; the return from the bottom was amplified in a wideband amplifier, displayed on an oscilloscope, and photographed with a still camera. Because of the apparent fluctuation of reverberation (to be described below), the camera shutter was kept open for a period of approximately 5 seconds and the maximum reverberation received during this interval was measured on the photographs; thus, what was observed was not <u>mean</u> reverberation but <u>maximum</u> reverberation over a 5-second interval. Indeed, this may be the more useful quantity from a practical viewpoint. Photographs of back-scattering for different tilt angles are shown in Figure 1.

The transducer, tilt shaft, and electronics were mounted on a small barge approximately 30 feet long by 15 feet wide. The tilt shaft was mounted on one end (Figure 2), and 31 feet away from the shaft, at the other end of the barge, a 3-foot Mark VI mine case (Figure 3) was mounted on an A-frame to serve as a reference target.

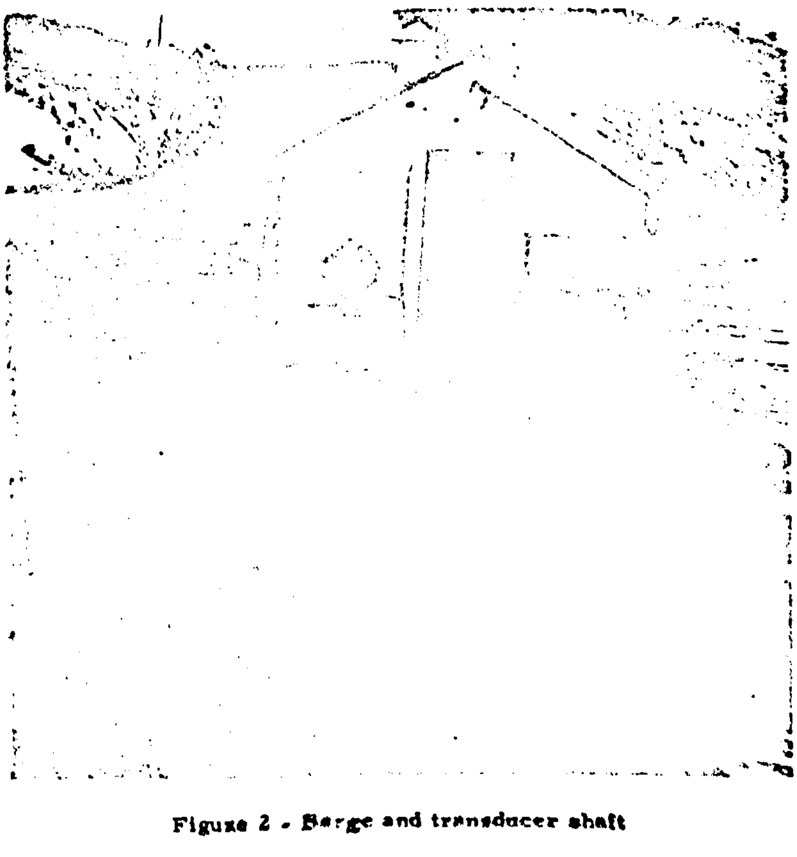

Figure 2 - Barge and transducer shaft

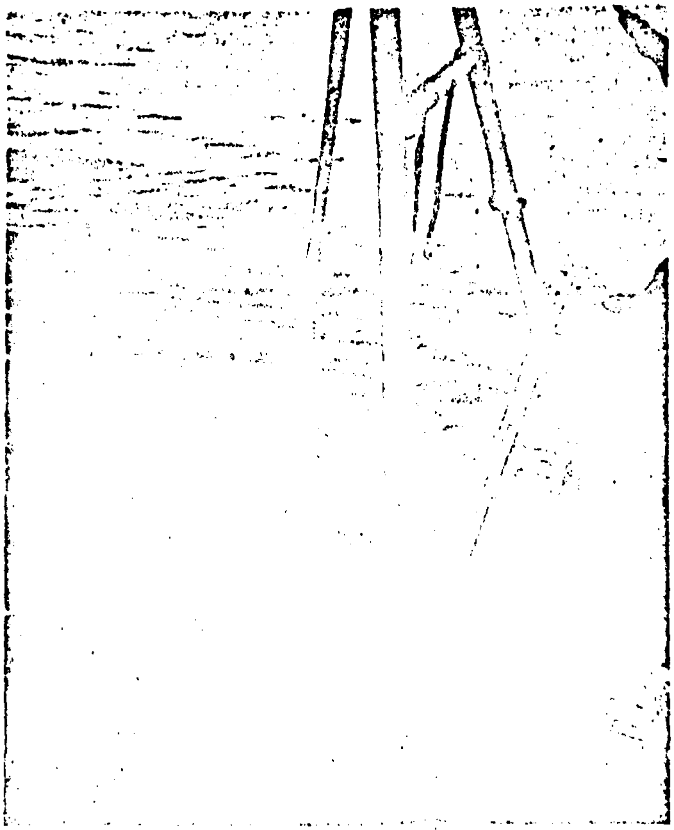

Figure 3 - Mark VI mine case mounted on an A-frame

The barge was towed to several locations (Figure 4) in Narragansett Bay, Rhode Island, and the reverberation was measured as a function of frequency, depression angle, and ping-length. The bottom types varied from rock (areas A, B) to sand (S3, S4) and mud (S5, S6) At all locations the water depth was great enough for the bottom to be entirely beyond the Fresnel zone of the transducer at the highest frequency used (60 kc).

SCATTERING STRENGTH: DEFINITION AND COMPUTATION

Let a plane wave of intensity I_i be incident upon an area one yard square of a scattering surface. Let the intensity of the scattered wave, measured at 1 yard in the direction back toward the source, be I_s. The ratio of these two intensities will be called the back-scattering strength or simply scattering strength, and will be denoted by S. Thus, referring to Figure 5,

$$S = 10 \log s = 10 \log \frac{I_s}{I_i} .$$

Since s refers to one square yard, the dimensions of s are $(\text{yards})^{-2}$. s is a function of the grazing angle θ between the incident ray and the surface.

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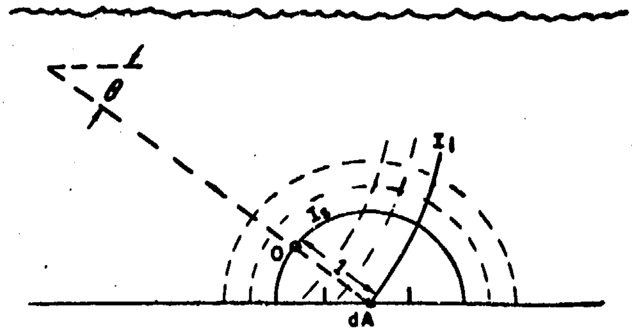
Figure 4 - Location of data stations in Narragansett Bay



Scattering intensity at O, one yard from a small area dA of bottom, is

$$I_s = I_i \cdot s \cdot dA$$

$$S \equiv 10 \log s$$

Figure 5 - Definition of scattering strength S

In using s to compute the intensity of back-scattering it is necessary to know the insonified area A which scatters sound back toward the source at any one instant. This area is determined by the beamwidth of the transducer and the pinglength. The product of s times A is the intensity of back scattering at unit distance from an area A, for unit incident intensity. The unit of distance is taken to be one yard and A is measured in square yards. For example, assume a searchlight transducer which emits short pulses and receives back-scattering from the bottom to have an intensity I_0 on its axis at a distance of one yard from the transducer. Then if we assume inverse square spreading, the intensity at the bottom at distance r yards will be $I_i = I_0/r^2$, and the intensity of scattering in the backward direction will be $I_s = I_i sA$. Back at the transducer, the scattering intensity will be

$$I_r = \frac{I_s}{r^2} = \frac{I_0}{r^4} sA. \tag{1}$$

In order to eliminate the need for knowing I_0 and the receiving sensitivity of the transducer, echoes from a reference "sphere" can be used to "calibrate" the back scattering. Suppose this sphere to have a target strength T* determined by its diameter and to be located at a distance r_s yards from the transducer. Its echo is of intensity

$$I_s = \frac{I_0 T}{r_s^4},$$

*The term target strength is customarily applied to 10 log T instead of T; it may, however, be applied to either 10 log T or T if the units are understood.

and the ratio of intensities of back-scattering to sphere echo is

$$\frac{I_r}{I_s} = \frac{sA}{T}\left(\frac{r_s}{r}\right)^4. \qquad (2)$$

In the present method the ratios I_r/I_s and r_s/r were measured from oscilloscope photographs, and A was computed from the geometry, enabling $S = 10 \log s$ to be determined if T is known.

The accuracy of the method obviously depends on the validity of the assumed value of the target strength T of the reference target. If the target is a perfect sphere, it is well known that $T = a^2/4$ where a is the radius of the sphere in yards. It is known also that for this expression to apply accurately, the sphere has indeed to be "perfect"; even slight departures from sphericity, such as dents and protuberances, affect the value of T. In the field a Mark VI mine case, a hollow ball of 3/16-inch steel about 3 feet in diameter and free from visible dents, was used. Lead weights were placed inside the ball to reduce its buoyancy, and then it was made watertight by welding. The ball was suspended by the block and tackle arrangement shown in Figure 3. Computation indicates that the echo from the supporting lines is negligible compared to the echo from the ball. The principal departure from sphericity at one place on the ball was a flat arming plate about 8 inches in diameter, which originally provided access to its interior. When the ball was hanging in the water, this plate was on the far side, away from the transducer. Although it is realized that this target is not a perfect one, it is believed that for this object the theoretical target strength of -12 db ±3 db is a reasonable approximation. This uncertainty is considered tolerable for the present experiment.

Some discussion is in order regarding the back-scattering strength S. It will be seen from Equation (1) that the product sA is analogous to the target strength T, and that the ratio of T to sA is the echo-to-reverberation ratio for a target, such as a mine, of strength T. Thus, S may be thought to be the target strength of a unit area square yard of bottom. In mine hunting, once the insonified area A is known, a comparison of the product (sA) with the target strength of the mine will reveal whether the mine will be detectable in the reverberation background. Or, in equipment design, s permits an estimate to be made of the maximum area, and thence the beamwidth-pulse length combination, which can be searched on any one ping without obscuring a target of assumed strength in the reverberation background.

During World War II, the NDRC[1] used the quantity $10 \log m''$ as a scattering parameter. Thus, m'' is defined as the amount of energy scattered per second into unit solid angle in the backward direction by a unit area of bottom, for unit incident intensity. In the echo ranging equation this parameter, in practical use with directional transducers, is coupled[2] with another parameter J_b, called the "bottom reverberation directivity index," which is defined mathematically in analogy with the ordinary directivity index of the transducer for an isotropic noise field. The relationship between m'' and the quantity s is

$$s = \frac{m''}{2\pi}. \qquad (3)$$

1 "Physics of Sound in the Sea," NDRC, Summary Technical Report Div. 6, Vol. 8, p. 252, 1946

2 Ibid, p. 264

Although it would appear that the distinction between S and m" is trivial, there is a considerable conceptual advantage in using the parameter s together with the instantaneous insonified area A, instead of m" and J_b. The geometrical "feeling" for the scattering problem which is thereby provided is most valuable in handling unusual situations.

COMPUTATION OF INSONIFIED AREA

With a given transducer using a given pinglength, it is necessary in a reverberation computation to find the insonified area A, which at any one instant scatters sound back toward the source. The particular instant chosen will be, for reasons of convenience and practical utility, the instant when the center of the ping reaches the range at which the axis of the transducer beam intersects the bottom. In other words (referring to Figure 6), for a searchlight transducer tilted downward at a small angle θ, the area A will be a portion of an ever expanding ring defined by the pinglength and beamwidth Φ; its area will be found at the instant when it is centered about P, the intersection of the axial ray and the bottom.

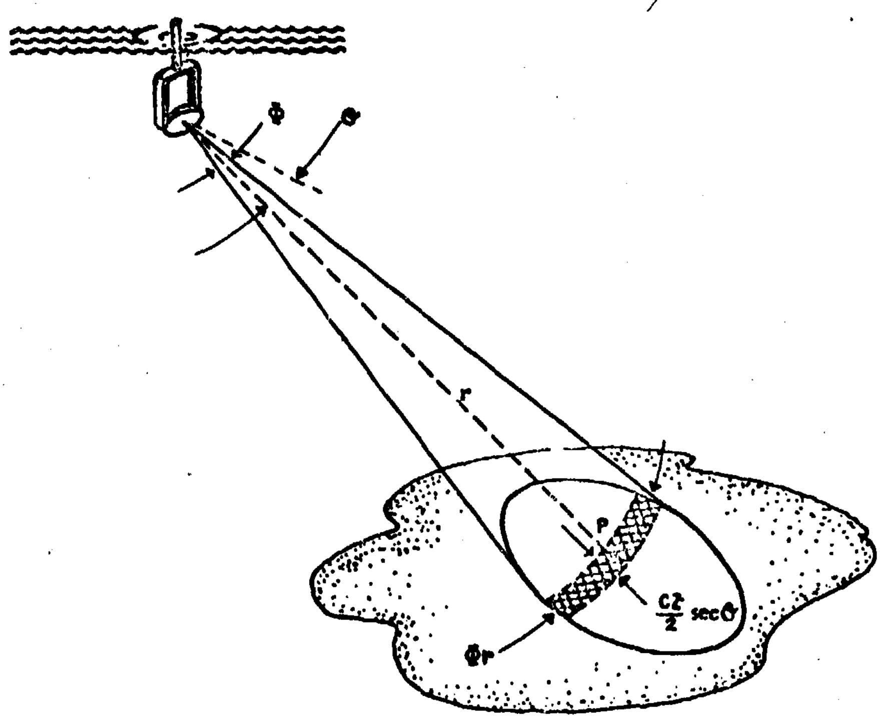


Figure 6 - Geometry of scattering for small angles

Two cases must be distinguished. At small angles of tilt, as in Figure 6, the area A will be determined in part by the pinglength. At high angles of tilt (Figure 7) the scattering area is independent of pinglength and is defined solely by the beamwidth Φ.

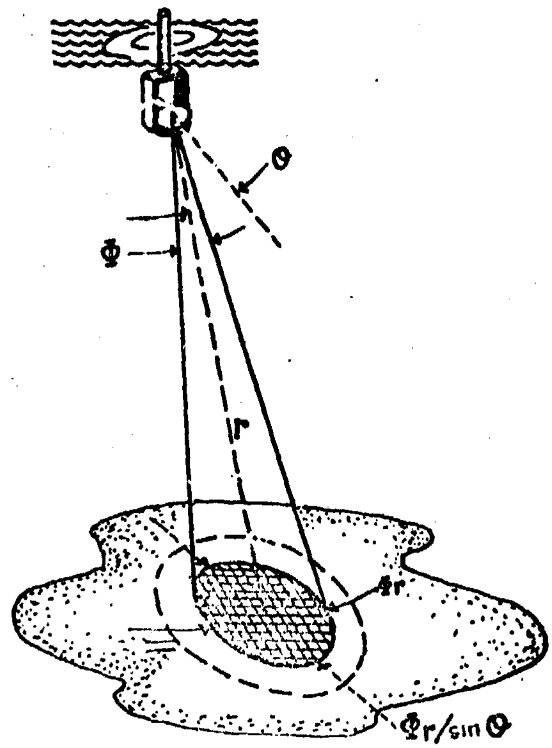


Figure 7 - Geometry of scattering for large angles

Let us assume the transducer has a beam pattern resembling that of a perfect searchlight, which has uniform intensity within a cone of total angle Φ and zero intensity outside Φ. It will be shown later how Φ can be determined from the actual beam pattern, or from the face diameter of the transducer. We will thus replace the true beam pattern by this ideal, equivalent searchlight beam of width Φ. At small angles θ of tilt, and at a range r, it will be seen from Figure 6 that

$$A = \Phi r \frac{c\tau}{2} \sec\theta \qquad (4)$$

where c is the velocity of sound and τ is the pinglength, provided r is large and both Φ and τ are small. At increasing angles of tilt, this area becomes larger and larger, until at some angle θ_0 it is equal to the area cut out by the beam alone.

At still larger tilt angles (Figure 7) the reverberating area A becomes an ellipse of major axis $\Phi r \csc\theta$ and minor axis Φr so that

$$A = \frac{\pi}{4}\left(\Phi r\right)^2 \csc\theta. \tag{5}$$

Equation (4) may be called the "small-angle" formula for A, and Equation (5) the "large-angle" formula. These two are equal at the transition angle θ_0 defined by

$$\Phi r \frac{c\tau}{2} \sec\theta_0 = \frac{\pi}{4}\left(\Phi r\right)^2 \csc\theta_0$$

$$\tan\theta_0 = \frac{\frac{\pi}{4}\Phi r}{\frac{c\tau}{2}}. \tag{6}$$

We must now justify the subterfuge of replacing the actual directivity pattern of the transducer by the ideal searchlight beam, and show how the width of the ideal beam is related to the actual pattern. At any one instant of time, the actual insonified area is an annulus of width $(c\tau)/2 \sec\theta = W$. This annulus is not insonified uniformly; a portion dA of it lying at an angle ϕ to the axis receives an intensity $q(\phi)$ relative to the intensity at the point where the beam axis intersects the bottom. Similarly, on reception the scattering received from dA produces a response $q(\phi)$ at the transducer terminals, relative to the response produced by an equal area centered at the intersection of the axis of the beam and the bottom. Thus, $q(\phi)$ is the intensity beam pattern function; for simplicity the transmitting and receiving response functions $q(\phi)$ are taken to be the same. If the annulus lies at range r,

$$dA = W r\, d\phi.$$

The intensity of the sound incident on dA, in terms of the axial intensity at unit distance, I_0, is $\frac{I_0}{r^2} q(\phi)$, so that the back scattered intensity at one yard from dA is

$$s\frac{I_0}{r^2} q(\phi)\, W r\, d\phi.$$

The response which this produces at the transducer is

$$s\frac{I_0}{r^4} q^2(\phi)\, W r\, d\phi.$$

If the transducer is in an infinite baffle, there is no rear response and only portions of the bottom such that $-\pi/2 < q < \pi/2$ are effective. The total response becomes

$$I_r = s\frac{I_0}{r^4} W r \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} q^2(\phi)\, d\phi.$$

Writing

$$\Phi = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} q^2(\phi)\, d\phi, \tag{7}$$

and replacing the area $W r \Phi$ by A we obtain

$$I_r = \frac{I_o}{r^4} s A$$

as in Equation (1).

Thus, if we define Φ in terms of the actual beam pattern $q(\phi)$ in accordance with Equation (7), all of the scattering appears to come from the area $A = W r \Phi$, as though the energy radiated by the transducer were confined to a cone of apex angle Φ with uniform intensity I_o at one yard.

When the transmitting and receiving directivity patterns are not the same, as in the case with scanning systems, the angle Φ is defined by

$$\Phi = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} q(\phi)\, q'(\phi)\, d\phi,$$

where $q(\phi)$ and $q'(\phi)$ are the two beam pattern functions.

Φ is related to the quantity $J_b = 10 \log j_b$ used by NDRC through the factor 2π,

$$\Phi = 2\pi j_b.$$

Since $s = m''/2\pi$, it follows that $j_b\, m'' = \Phi s$ and the reverberation computed from either pair of parameters is the same.

The evaluation of Equation (7) has been accomplished[3] for certain types of transducers. For a circular piston transducer in an infinite baffle of radius "a" at wavelength λ,

$$q(\phi) = \left[\frac{2 J_1(u)}{u}\right]^2,$$

where

$$u = \frac{2\pi a}{\lambda} \sin\phi.$$

Hence,

$$\Phi = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} q^2(\phi)\, d\phi = 2\int_0^{\frac{\pi}{2}} q^2(\phi)\, d\phi = \frac{\lambda}{\pi a}\int_0^{\frac{2\pi a}{\lambda}} \left[2\frac{J_1\, u}{u}\right]^4 du/\cos\phi$$

If $2\pi a/\lambda$ is ≥ 3, it can be shown that this integral has approximately the value

$$\Phi = 0.387\, \lambda/a \qquad (8)$$

[3] "The Discrimination of Transducers Against Reverberation," UCDWR Report U75, May 1943

In terms of the beam pattern, Φ in degrees is related to the angle ψ in degrees between the 3-db down points according to

$$\Phi = 0.78\,\psi. \tag{9}$$

Figure 8 shows the beam pattern of the transducer used in the present experiment at a frequency of 46 kc. The radius of the active face of this transducer was $6\frac{1}{4}$ inches. Hence, for this frequency we find from Equation (8) that $\Phi = 4.5°$; from the beam pattern, using Equation (9), $\Phi = 4.3°$. Figure 9 shows Φ as a function of frequency for this transducer, using values obtained from measured beam patterns.

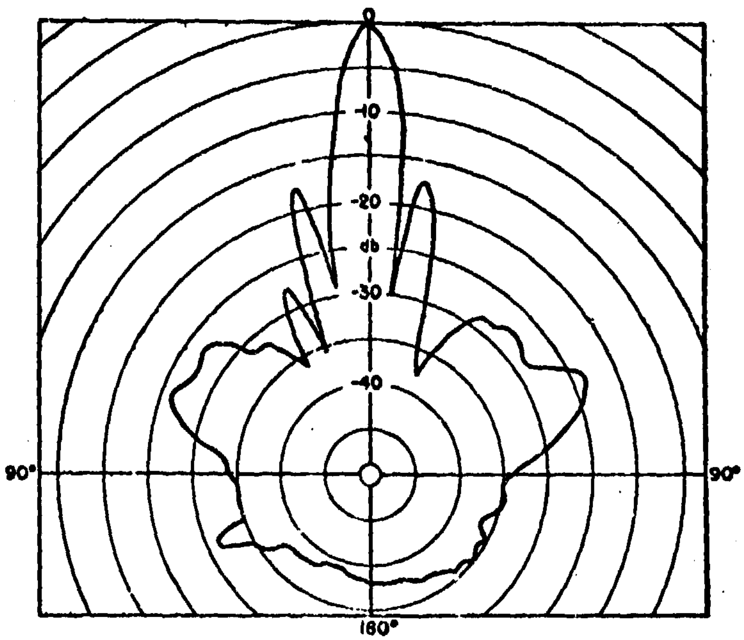


Figure 8 - 46-kc beam pattern, NRL-XQB-27 frequency transducer

REDUCTION OF DATA

At each of the locations in Narragansett Bay (Figure 4), still-camera photographs were taken with the shutter open for a 5-second period for various combinations of frequency, tilt angle, and pinglength. These photographs showed a maximum in backscattering at a time very nearly corresponding to the slant distance along the axial ray between the transducer and the bottom. This maximum was measured in arbitrary scale units and compared with the amplitude at that frequency of the echo from the Mark VI mine case located 31 feet from the transducer. The reverberating area A in square yards was computed from the value of Φ (Figure 9), the slant range to the bottom, the tilt angle, and the pinglength. In this computation, either the small-angle formula (Equation (4)) or the large-angle formula (Equation (5)) was used, depending on whether the tilt was less than, or greater than, the value of transition angle θ_0 (Equation (6)). With (1)

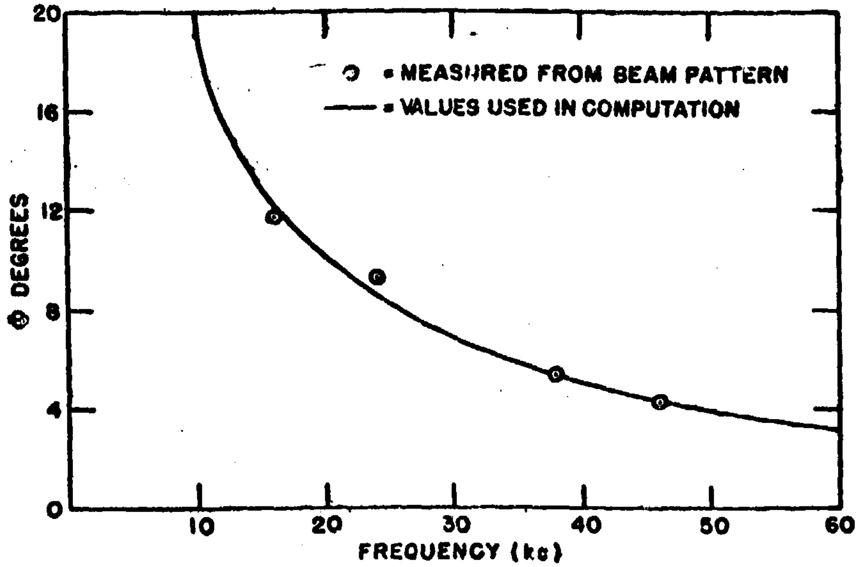


Figure 9 - Equivalent angle Φ vs. frequency transducer NRL-XQB-27

the ratio of intensities I_r/I_s of back-scattering amplitude to mine case echo (2), the ratio r/r_s of the slant distance to the bottom compared to the distance to the mine case (3), the theoretical value of T (-12 db) of the target strength of the mine case, and (4) the scattering area A, the scattering strength S was computed from

$$S = 10 \log s = 10 \log\left(\frac{I_r}{I_s}\right)\left(\frac{r}{r_s}\right)^4 \frac{T}{A}$$

following Equation (2). A total of 68 rolls of 35-mm film were exposed at the eight locations shown in Figure 4, giving an average of 300 individual scattering measurements at each location.

VARIATION OF SCATTERING WITH PINGLENGTH

By referring to Equation (4), it will be seen that the area A, and therefore the back-scattering intensity, should vary linearly with pinglength, τ, below the transition angle θ_e and be independent of pinglength when the tilt angle is greater than θ_e. That this actually occurs is shown in Figure 10, where each plotted point results from a single reverberation photograph, and the theoretical variation with pinglength is indicated. An idea of the variability of individual measurements is also evident. Many other measurements have shown that there is no apparent dependence of the computed value of S upon pinglength. It thus appears that the variation with pinglength is in agreement with theory based on simple geometrical considerations.

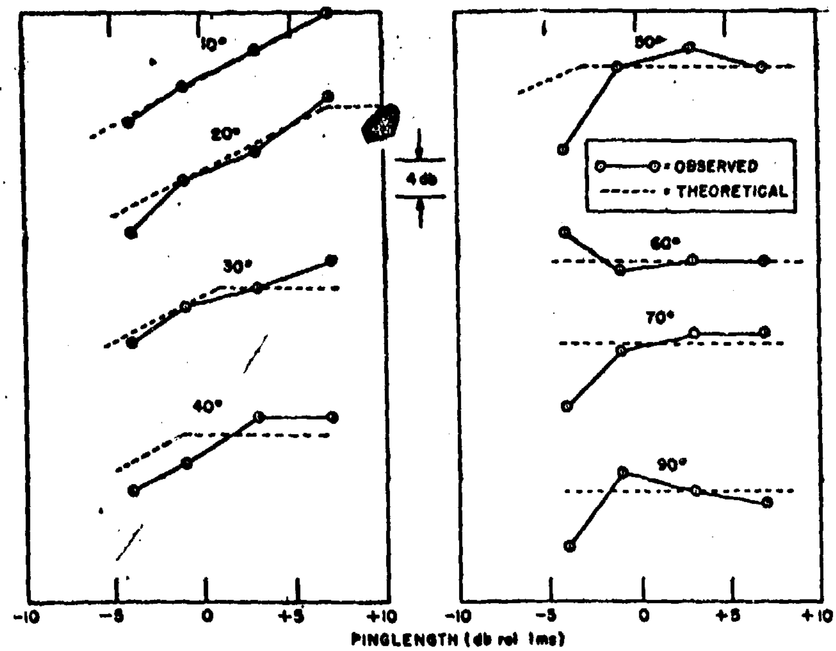


Figure 10 - Variation with pinglength at various grazing angles at 55 kc in area A

VARIATION OF SCATTERING WITH GRAZING ANGLE

This type of variation was studied by keeping the pinglength and frequency constant, and changing the tilt of the transducer at about 10-degree intervals between 10° and 90°. Figure 11 shows the variation of S with grazing angle as measured at all locations (Figure 4) except location D.I.H., where this type of data was not obtained. Each plotted point is the average of several to many individual measurements.

It is apparent that S decreases with decreasing grazing angle for all types of bottom encountered. This general variation is well known, being first observed in World War II;[4] it applies also in radar in connection with the back-scattering of radio waves from the sea surface[5] and has been observed in model experiments using high-frequency sound.[6]

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[4] "Physics of Sound in The Sea," NDRC Summary Technical Report Div. 6, Vol. 8, pp. 314-318, 1946

[5] "Propagation of Short Radio Waves," M.I.T. Rad. Lab. Series, Vol. 13, pp. 503-510, New York: McGraw-Hill, 1951

[6] University of Texas, Defense Research Lab. Monthly Progress Report (Confidential), December 1952

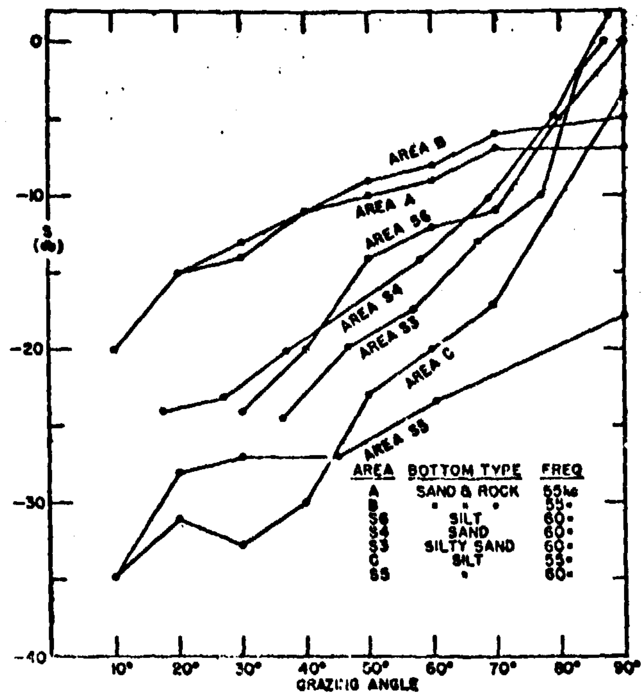

Figure 11 - Variation of back-scattering strength with grazing angle at frequencies of 55 and 60 kc

There is st.ong tendency for the scattering to depend upon the type of bottom. The hard, rocky bottoms of areas A and B have the highest back-scattering and the silty bottoms the least. The rate of decrease of S with decreasing grazing angle also appears roughly to depend on bottom type—the softer bottoms having a faster rate of decrease. The sand and silt bottoms, except for area S5, tend to have greater back-scattering at normal incidence ($\theta = 90^\circ$) and fall off faster with decreasing θ. For the rocky bottoms A and B, S varies approximately as $\sin^n \theta$ with n about 2.0. Some of the physical characteristics of the bottom materials, as given by analyses of core samples, are listed in Table 1. The technical term "silt" is most nearly equivalent to "mud" in its ordinary usage.

VARIATION WITH FREQUENCY

The frequency variation of back-scattering was observed by comparing the ratio of intensities of scattering to sphere echo at fixed tilt angle and pinglength for a number of frequencies between 10 and 60 kc. The response of the transducer prevented working outside these frequency limits. Figure 12 shows 10 log S at $\theta = 30^\circ$ plotted against frequency for four of the locations. Since the data points do not lie on smooth curves, there is no clear evidence of a strong dependence on frequency. The scattering at the silty areas S5 and C might be said to show a slope of about 2 db per octave; at the other two

areas, B and D.I.H., S seems to be independent of frequency. This lack of a clear frequency variation is in agreement with the results of a wartime investigation[7] of scattering at 10, 20, 40, and 80 kc at 30° grazing angle.

TABLE I
Bottom Characteristics at the Data Stations

Area	Bottom Classification	Density		Water Content (%)	Organic Content % (Based on weight of dry sample)
		Wet	Dry		
A and B (Fort Wetherell)	Silty sand and rock	1.6	2.9	31	2.2
C (Mackerel Cove)	Very fine sandy silt	1.8	2.3	31	1.7
D.I.H. (Dutch Island Harbor)	Highly organic silt and shell	1.3	2.1	60	7.4
S3	Clean, slightly silty sand	1.9	2.6	24	0.7
S4	Very silty fine sand	1.6	2.9	33	1.2
S5	Medium organic clayey silt	1.5	2.8	51	4.3
S6	Medium organic silt	1.4	2.3	53	4.3

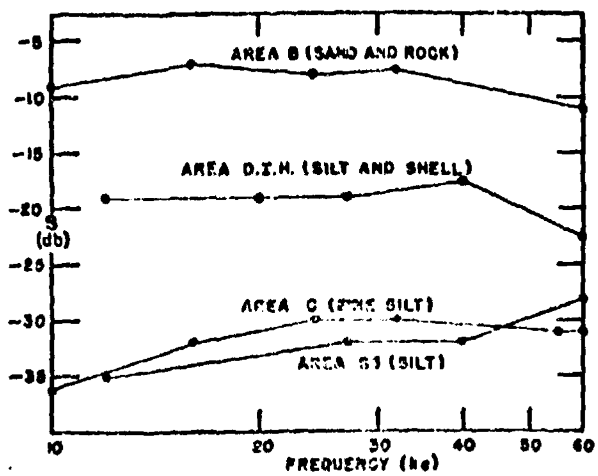

Figure 12 - Variation of back-scattering with frequency at a grazing angle of 30°

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7 "Bottom Reverberation: Dependence on Frequency," UCDWR Report U-79, 1943

CAUSES OF SCATTERING

It is interesting and important to consider whether the back-scattering of sound by a natural bottom is due primarily (1) to its roughness, or (2) to its particulate nature, that is, the fact that the bottom is granular and consists of numerous scatterers in the form of sediment particles. This is not entirely an academic matter, for it determines the method of classifying bottoms as to scattering ability.

From the well-known dependence of scattering on bottom type it would appear that the material of the bottom itself is the principal cause of scattering. This has been the tacit assumption of the model studies at the University of Texas and is the subject of a recent theoretical paper.[8] However, there is evidence in the present field data to show that the bottom contour may play an even more important role. In the case of the rocky bottoms, the variation of back-scattering with angle is approximately like the Lambert's Law variation to be expected from a perfectly diffuse reflector. Indeed, a photograph of the bottom at Location B (Figure 13) taken by the Woods Hole Oceanographic Institution with a special camera,[9] shows the bottom to be quite rough, with rock and shell protruding through a sandy veneer. Scattering from such a bottom must be the result of its roughness. Another bit of evidence from Figure 11 is that there is no indication of an increased return at normal incidence. If the bottom were a predominantly specular reflector, there should exist a rapid increase in S within the beamwidth of the main lobe as the grazing angle approaches 90°. The absence of such an increase indicates a rough, diffuse-reflecting bottom. The absence of a strong frequency variation is also consistent with roughness-caused scattering. The field data thus point to roughness as being the important source of back-scattering. However, it will require specially designed field experiments, together with collateral data such as photographs of the bottom to adequately study this subject.

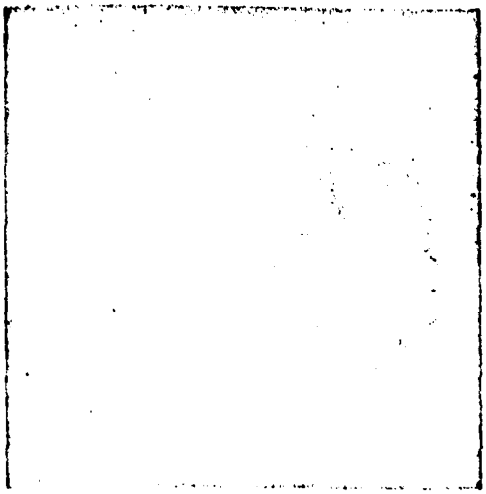

Figure 13 - Photograph of bottom at area B

[8] Nolle, A. W., "Backward Scattering of Sound in a Fluid from the Boundary of a Granular Medium." Paper read at the San Diego meeting of the Acoustical Society of America, 1952

[9] Owen, D. M., "Two Deep Sea Cameras Assembled for Coastal, Harbor Survey, and Mid-Level Photography," WHOI Reference 52-62, 1952

FLUCTUATION OF SCATTERING

The ping-to-ping fluctuation of scattering level was investigated in a preliminary way by photographing individual pings with a movie camera having its shutter speed synchronized with the ping repetition rate of 16 per second. On each film frame, the amplitude of the scattering peak was measured and converted into db. One example of a scattering versus time plot is given in Figure 14. During the 5½-second interval shown, the scattering intensity varied through a range of 12½ db, with the maximum values about 5 db greater than the mean. Other fluctuation plots indicated that the maximum mean ratio lay in the range 3 to 5 db.

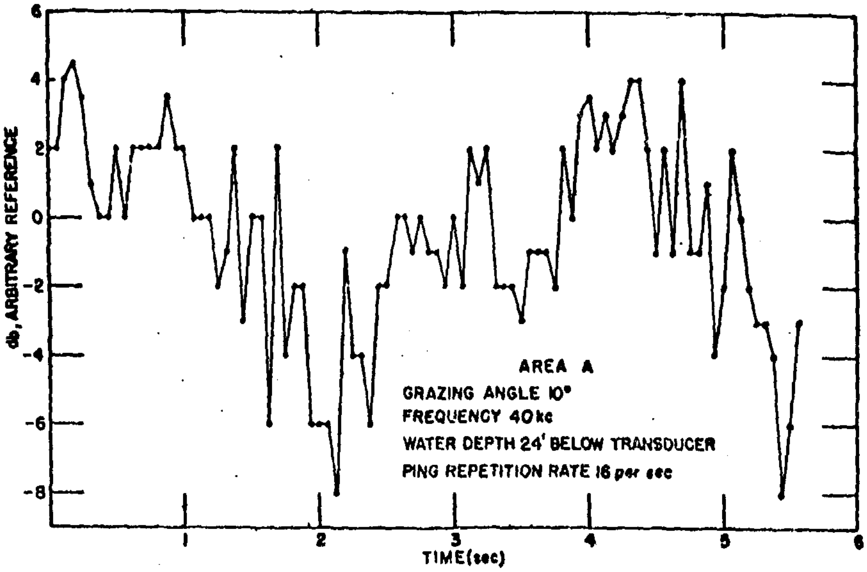

Figure 14 - Time variability of scattering

It seems reasonable to attribute this fluctuation to the motion of the barge. When the barge moves, however slightly, so does the insonified area on the bottom, and the scattered returns from individual scatterers will interfere differently at successive instants of time. The extent and rapidity of the fluctuation, when correlated with the extent and rapidity of the motion of the barge, can provide valuable information as to the size and distribution of the scatterers on the bottom. It also has bearing on the ability to detect a steady target echo in the variable scattering background.

COMPARISON WITH OTHER VALUES

Our knowledge as it existed at the end of World War II regarding back-scattering of bottoms is summarized in Reference 1. Values of S that are stated to be "over-all mean" values at 10° grazing angle are as follows:

Bottom Type	S
ROCK	-28 ± 5 db
MUD [SILT]	-35 ± 5 db
SAND AND MUD	-36 ± 5 db
SAND	-40 ± 5 db

These values are copied from Table 7 of Reference 1, with a correction of 10 log 2π = -8 db applied in order to convert 10 log m" to S, in accordance with Equation (3). A comparison with the present results shown in Figure 11 shows that the above values are lower by approximately 3 to 10 db. This is roughly the difference between the "mean" and the "maximum" values estimated above. It should be pointed out that much of the wartime data was obtained with horizontally directed transducers, so that the angle of incidence at the bottom was conjectural; in addition, no systematic measurement variation with angle of incidence was attempted.

More recent data is contained in a progress report of H. M. Underwater Detection Establishment, Portland, England.[10] Scattering levels were measured as a function of range over various types of bottoms, and compared with computed levels of the echo from an 18-inch sphere. Plots of scattering and echo level versus range are given. Knowing the transducer beamwidth and pinglength, these plots allow values of the scattering strength S to be computed as a function of angle. In making this conversion, iso-velocity water was assumed and ray-bending was neglected. Figure 15 gives S versus grazing angle as computed from the UDE data, together with some of the points from Figure 11. This UDE data is particularly valuable in providing information in the important region of grazing angle below 10°. There is reasonable agreement between the British data and that obtained in Narragansett Bay. The straight lines drawn through the British points in Figure 14 indicate that s varies approximately as the 1.5 power of grazing angle; thus, bottom reverberation should fall off with range for small grazing angles at a rate proportional to the -4.5 power of the range. Since the target echo varies as the -4th power of the range, this means that bottom reverberation dies away slightly faster with range (or time) than the target echo. It should be pointed out that the British values should be higher than the true "mean" values by perhaps 6 db, because of multiple surface-reflected paths existing with a vertically widebeam transducer.

EXAMPLE OF USE OF THE RESULTS

Let us consider by an example how the value of S can be used to make a prediction of detection range for a hypothetical equipment over a muddy bottom such as areas C or S5. Let the transducer be of the searchlight type having both transmitting and receiving beams $2\frac{1}{2}°$ wide, and using a pinglength of 1 ms, or 0.8 yard. Assume a tilt angle of 10° in 100 feet of water. If we take $\phi = 2\frac{1}{2}° = 0.043$ radian and compute the slant range to be 100 ft/tan 10° = 570 feet or 190 yards, the area that back-scatters sound (at the instant when the center of the ping lies at the slant range) is

$$(0.043)(190)(0.8) = 6.5 \text{ square yards} = 8.1 \text{ db rel. } 1 \text{ yd}^2.$$

10 Great Britian UDE Scientific and Technical Progress Report 1952/1, 1952

Referrin- ') Figure 11 for area C at 10°, we find S = -33 db. The product (sA) is then -33 + 8.1 = -25 db. This value is equivalent to the target strength of the smallest target that can be detected in the scattering background, if the recognition differential is taken at zero db. If we use a value of -18 db as the mean target strength of a mine, the mine echo will be 7 db higher than the scattering background under the assumed conditions. A similar calculation for a smaller value of tilt will yield another value of echo-to-background ratio, and the predicted range, at which this ratio equals the recognition differential, can be found by interpolation or extrapolation. In performing such calculations for an actual field situation, care should be taken to allow for ray-bending at small tilt angles caused by velocity gradients, and for surface-reflected back-scattering from the bottom. In equipment design, the above calculation would be performed backwards.

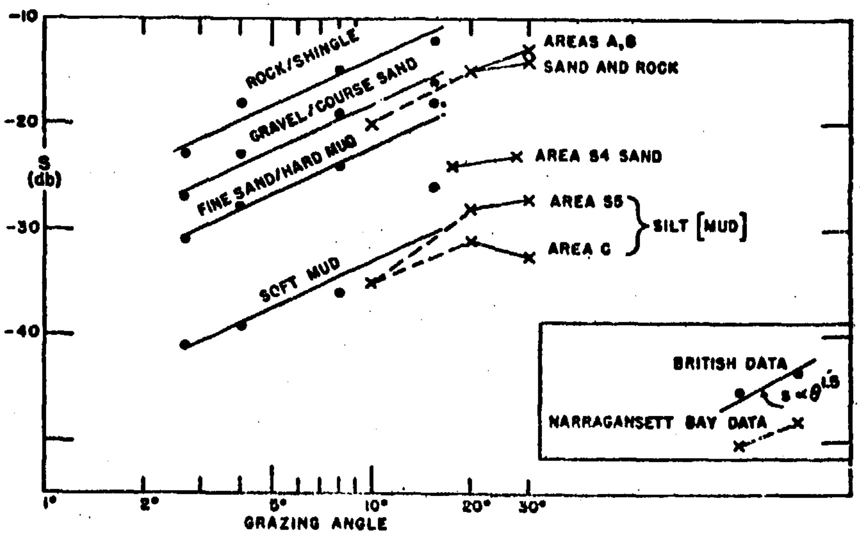

Figure 15 - Comparison of Narragansett Bay data with British values, computed from reverberation vs. range data in UDE Progress Report 1952/1

CONCLUSIONS

A small program of scattering measurements in Narragansett Bay has obtained some values of scattering strength for different bottoms, frequencies, and tilt angles that appear to be useful for planning purposes. The results are essentially preliminary; in order to have confidence in range predictions and in the performance of rationally designed equipment, additional measurements are required. It is especially important to extend the data upward in frequency and downward in grazing angle, so as to cover the entire range of interest in mine hunting.

There is evidence that bottom type, whether sand, mud, etc., as revealed by particle-size analyses, is at best only a poor criterion of scattering strength. For example, a sandy bottom may be a very intense scatterer of sound if it is ripple-marked. If roughness, rather than particle-size, is the important factor in scattering as the data seem to

indicate, the bottom type shown by standard analyses is only an indirect indicator of scattering strength. Bottom photographs, which may be said to result from the back-scattering of light, might provide excellent clues to the behavior of the bottom to sound. If such is the case, it would appear that harbor surveys pertaining to acoustic mine hunting must measure scattering directly with sound, rather than indirectly by some other method, and so provide scattering contour charts to show the areas where mines can, or cannot, be located with present systems.

ACKNOWLEDGMENTS

The work has been a cooperative project in that several groups and individuals participated in an active way. Mr. John R. Nixon and Mr. C. U. Mulholland of the Narragansett Marine Laboratory carried out much of the field work, obtained bottom cores, and made sediment analyses. Mr. D. M. Owen of WHOI obtained stereo photographs of the bottom at two locations. The personnel of Project BEAVERTAIL, at the USN Radar Facility, Jamestown, R. I., provided great assistance in setting up the experiment. Dr. Charles E. Mongan of the Edo Corporation participated in a portion of the data collection and provided stimulating discussions. To all of the above, the indebtedness of the author is gratefully acknowledged.

* * *

UNITED STATES GOVERNMENT

memorandum

7103/122

DATE: 31 October 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

AD-016 696

VIA: Code 7100

REF: (a) NRL Confidential Report #4195 by R.J. Urick, 23 July 1953 (U)

1. Reference (a) is a report on the acoustic scattering of the sea bottom in support of locating bottom mines. The scattering data was obtained from eight locations in Narragansett Bay in the frequency range of 10-60 kHz and between 10° and 90° grazing angle. The locations tested included bottom types from rock through sand to mud. The report includes scattering theory, equipment characteristics, test procedures, and resulting scattering data.

2. The science and technology of this report are currently well known in underwater acoustics.

3. Based on the above, it is recommended that reference (a) be declassified with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R Franchi 11/4/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

Completed
20 Mar 2000
B.W.

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